The NuMI Neutrino Beam Facility

I. Design of 0.4MW Beam
II. Status of Construction
III. Capability for 0.8,1.6MW

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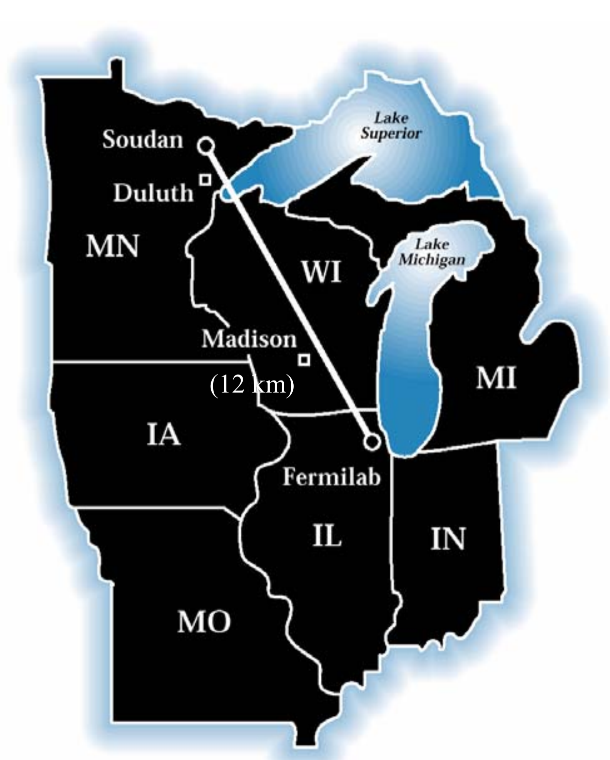
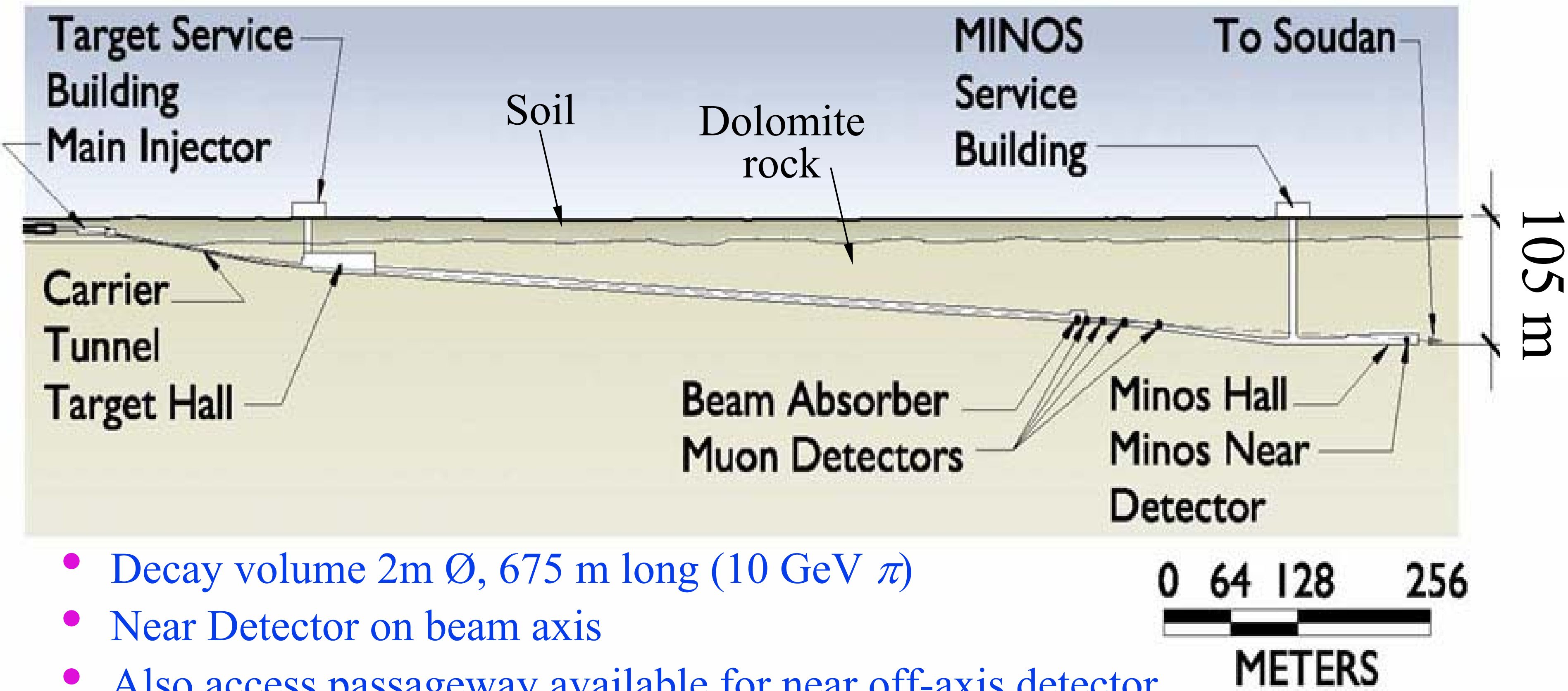
for the
NuMI/MINOS Collaboration



- NuMI has 400kW primary proton beam
  - 120 GeV
  - 8.67 μsec spill
  - 1.9 sec rep rate

- Beam Axis 3.32° into the ground at FNAL, exits at Canadian border.
- 2° off-axis in southern Canada or northern Wisconsin (L = 530 – 950 km)

NuMI Tunnel



- Decay volume 2m Ø, 675 m long (10 GeV π)
- Near Detector on beam axis
- Also access passageway available for near off-axis detector
- Beamline passes through 3 acquifers

What You'd See Above Ground Now…

Target Station Service Building

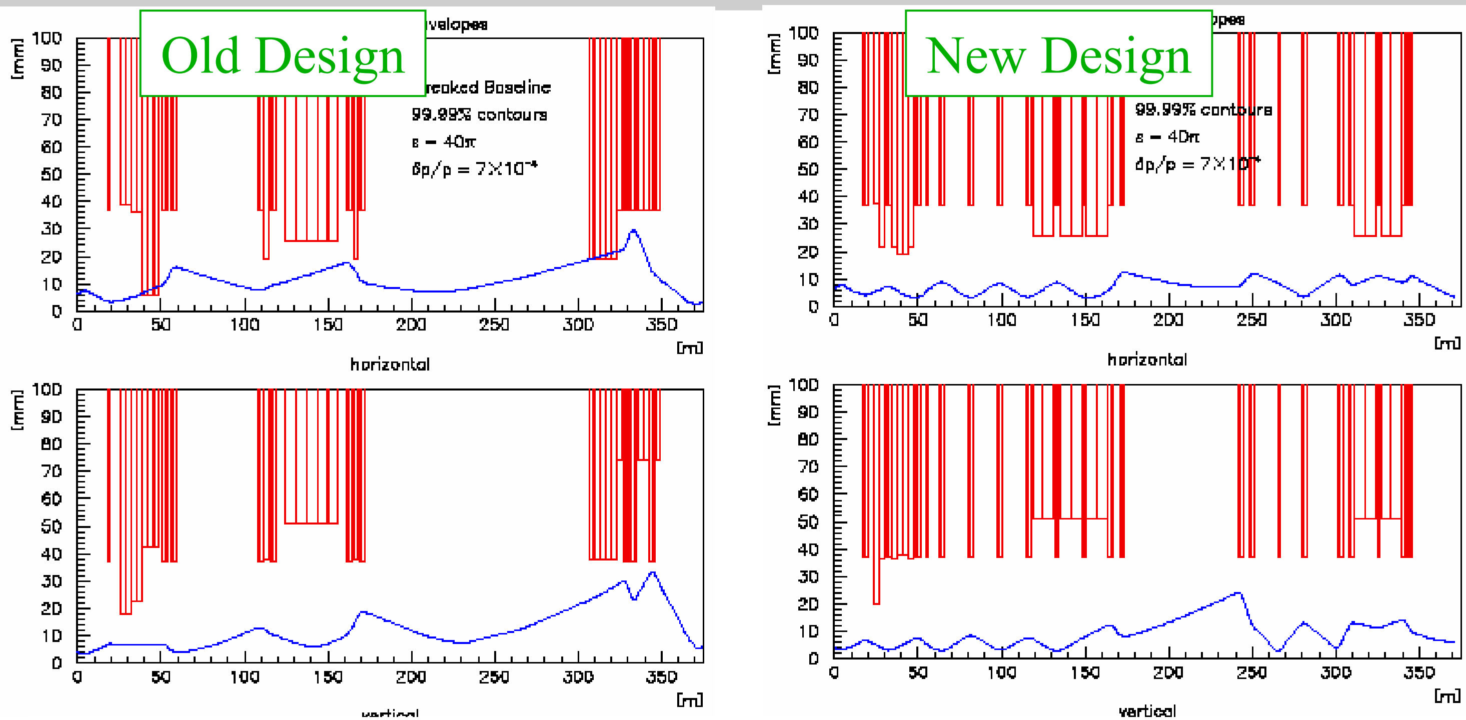
Obtained occupancy of building and the underground target area from contractor October 20, 2003

MINOS Service Building

Expect to obtain occupancy from contractor Feb 16, 2004

What You'd See Below: Near MINOS Hall

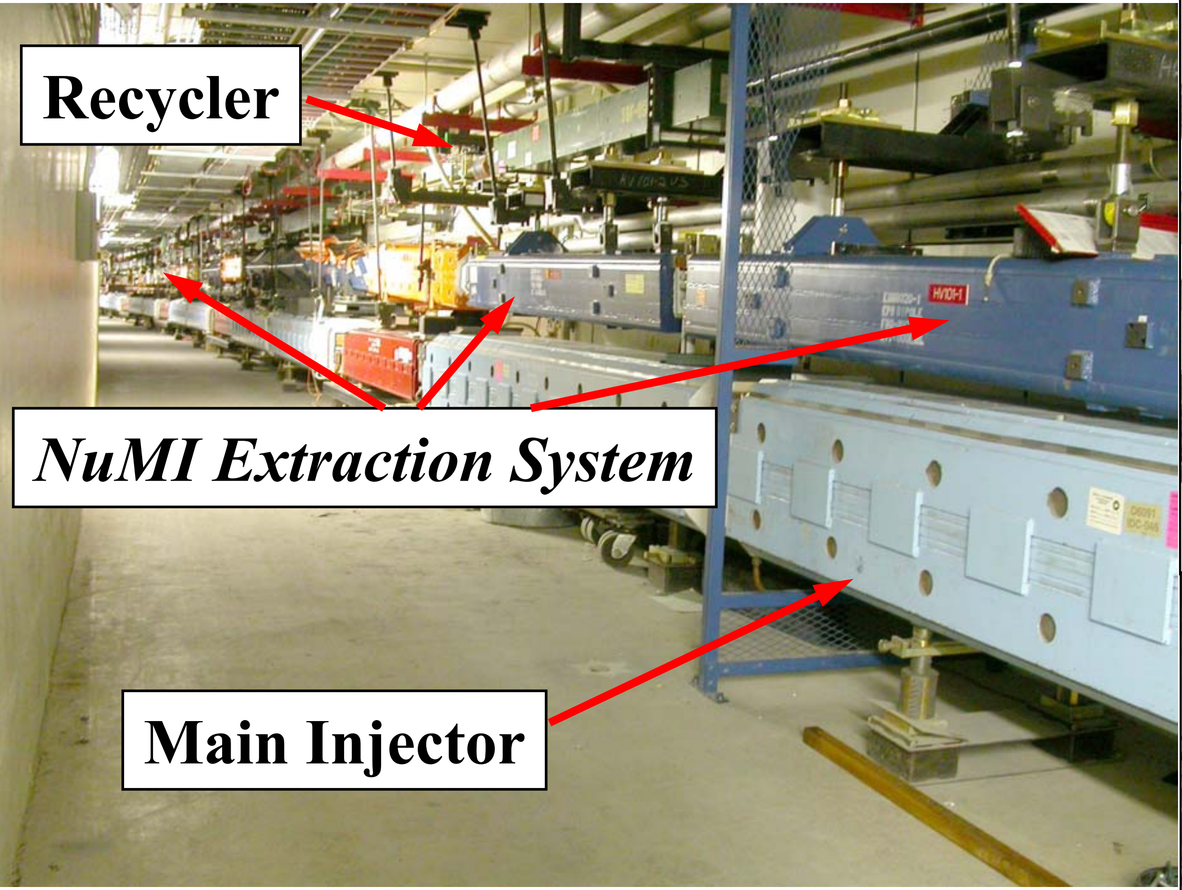
Improved Extraction Channel

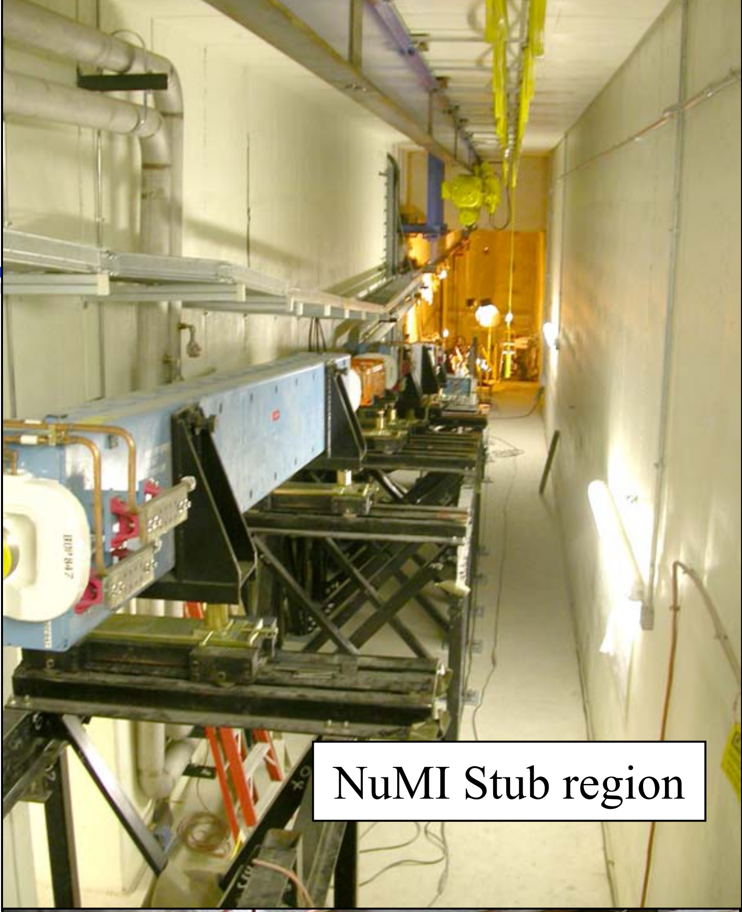


figures courtesy S.Childress

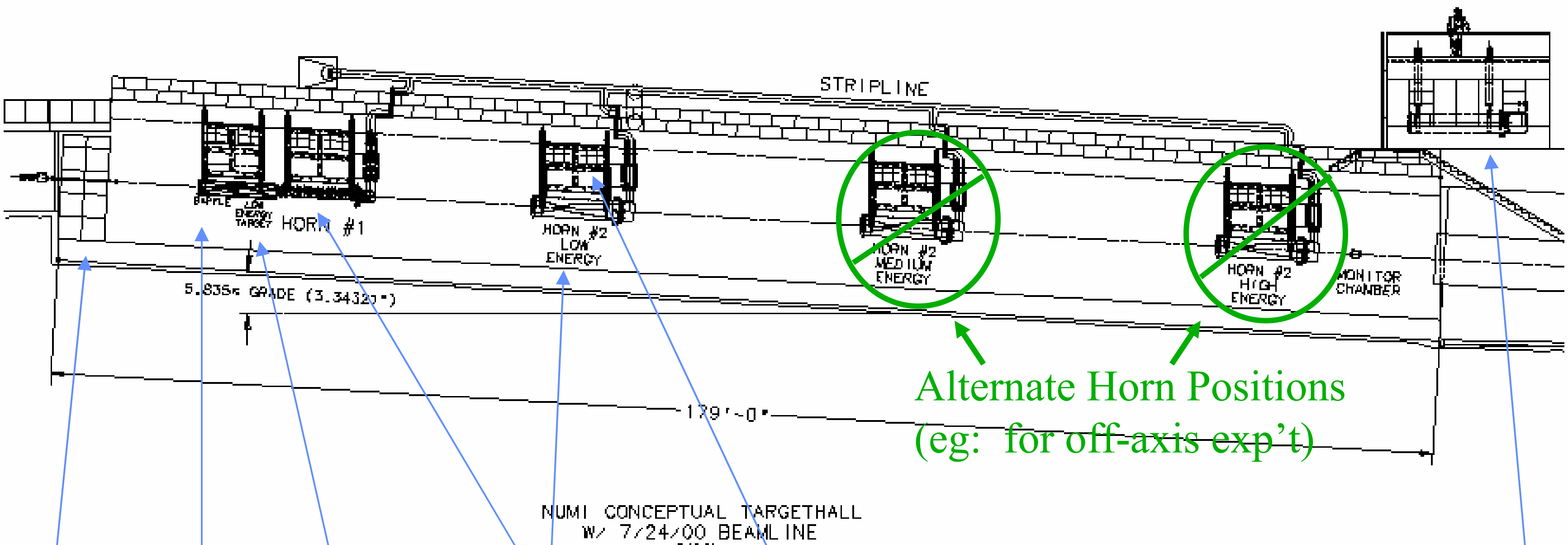
- Added focusing in 40m drift region through soil-rock interface.
- Wanted more conservative design
  - »Emittance growth with intensity
    - ε_h, $\varepsilon_v \sim 25\pi$ mm-mrad measured in MI (design for 40π)
    - ε_l, $\sim$ 0.5-0.6 eV-sec measured in MI (design for 1 eV-sec) ($\delta p/p \sim 5 \times 10^{-4}$)
  - »Potential routes to improve proton intensity include batch ‘stacking’
  - Plan for 2-4 × larger emittances.

Installed Primary Beam Magnets





Target Hall



Beamline Component Positioning Modules

Two Types of Magnetic Focusing Horns

Pion Production Target (plus readout of target, vacuum pump)

Baffle to protect horn from beam accidents

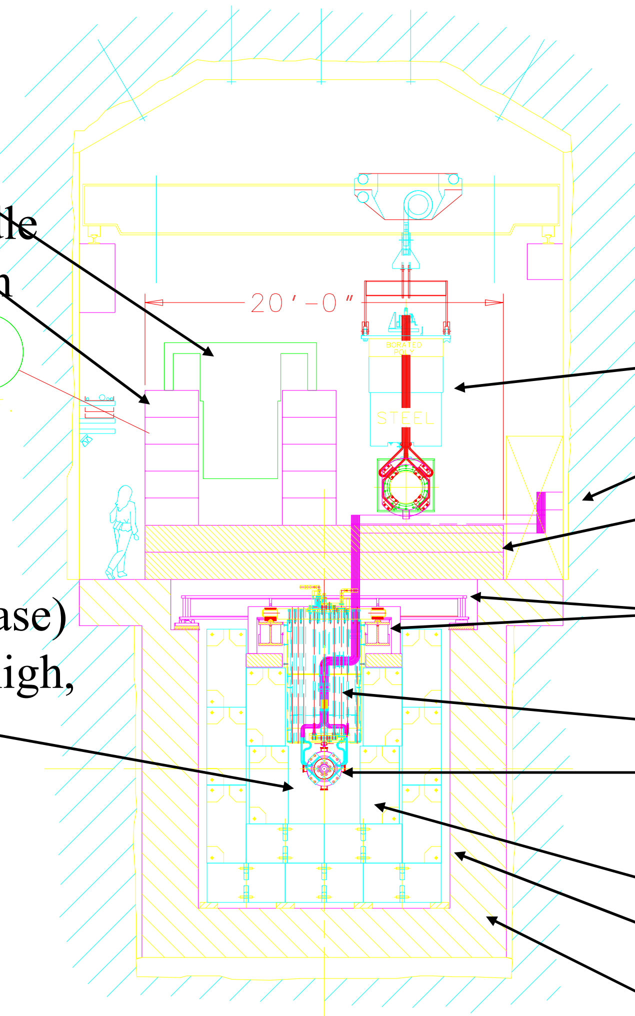
Target Hall Radiation Shielding

Radioactivated component work cell

NuMI Target Hall

- Shielding protects
  groundwater below
  personnel above
- Air volume sealed, recirculated

Temporary Stackup of removed shielding
Steel from module middle
Concrete from over horn



Horn+Module in transit

Stripline

Concrete Cover

"Carriage" - Module Support Beams

Horn Shielding Module

Horn

Beam passageway (chase) is 1.2 m wide x 1.3 high, forced-air-cooled

Steel Shielding

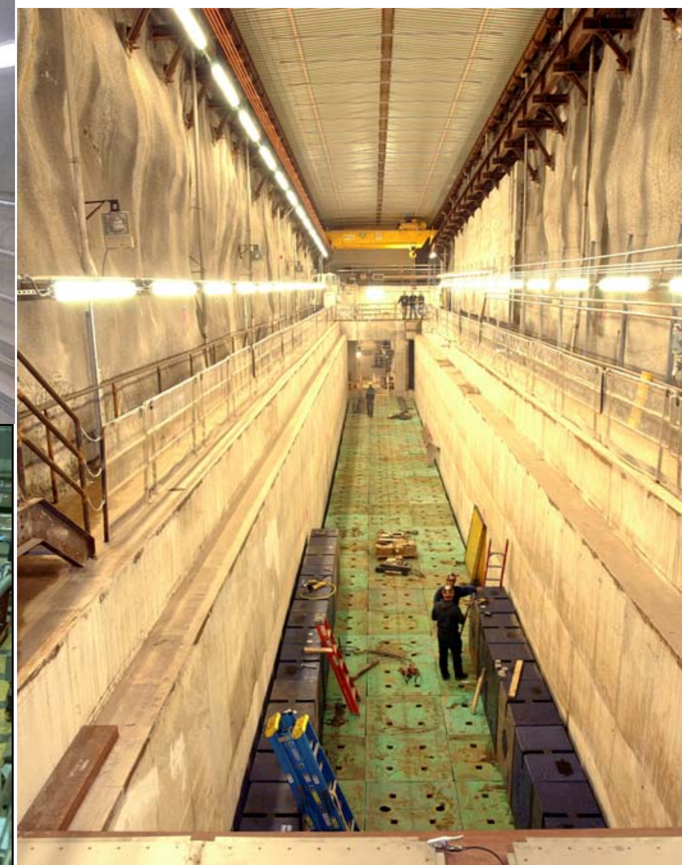
Air Cooling Passage

Concrete Shielding

Target Hall Progress

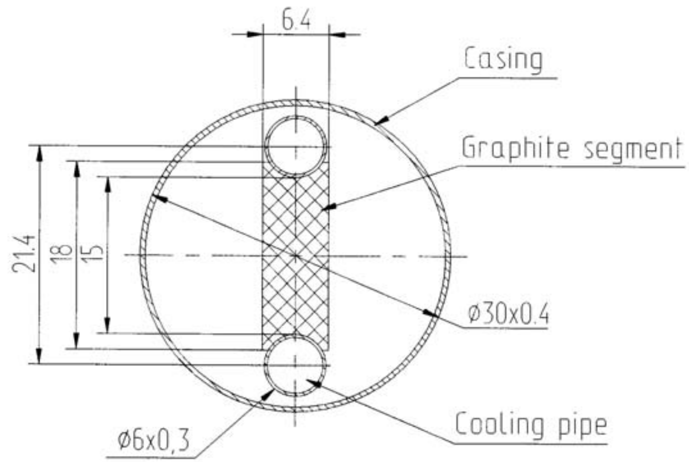
Target Hall after Contractor completion

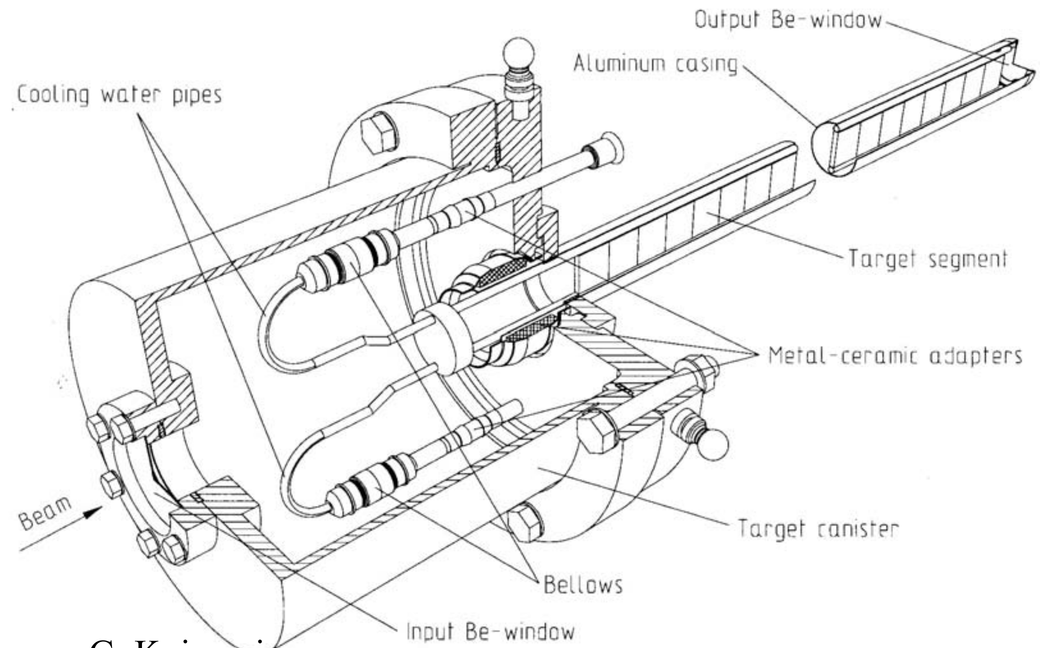
Target Hall shielding installation



Hotcell pre-assembly

NuMI Production Target





FNAL design team

J.Hylen, K.Anderson

FNAL beam test

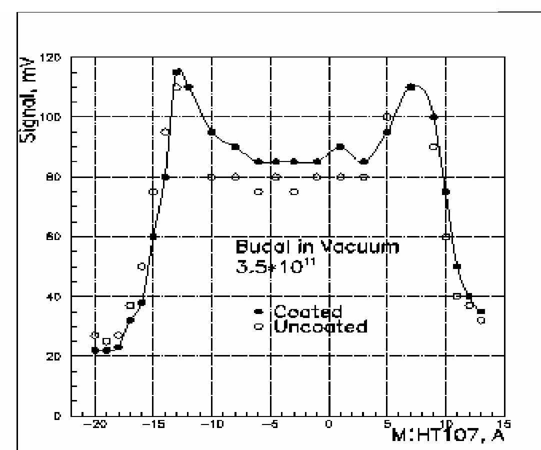
J.Morgan, H.Le, Alex Kulik, P. Lucas, G. Koizumi

IHEP Protvino design team:

V.Garkusha, V.Zarucheisky

F.Novoskoltsev, S.Filippov, A.Ryabov, P.Galkin, V.Gres, V.Gurov, V.Lapygin, A.Shalunov, A.Abramov, N.Galyaev, A.Kharlamov, E.Lomakin, V.Zapolsky

Target read-out
Budal mode

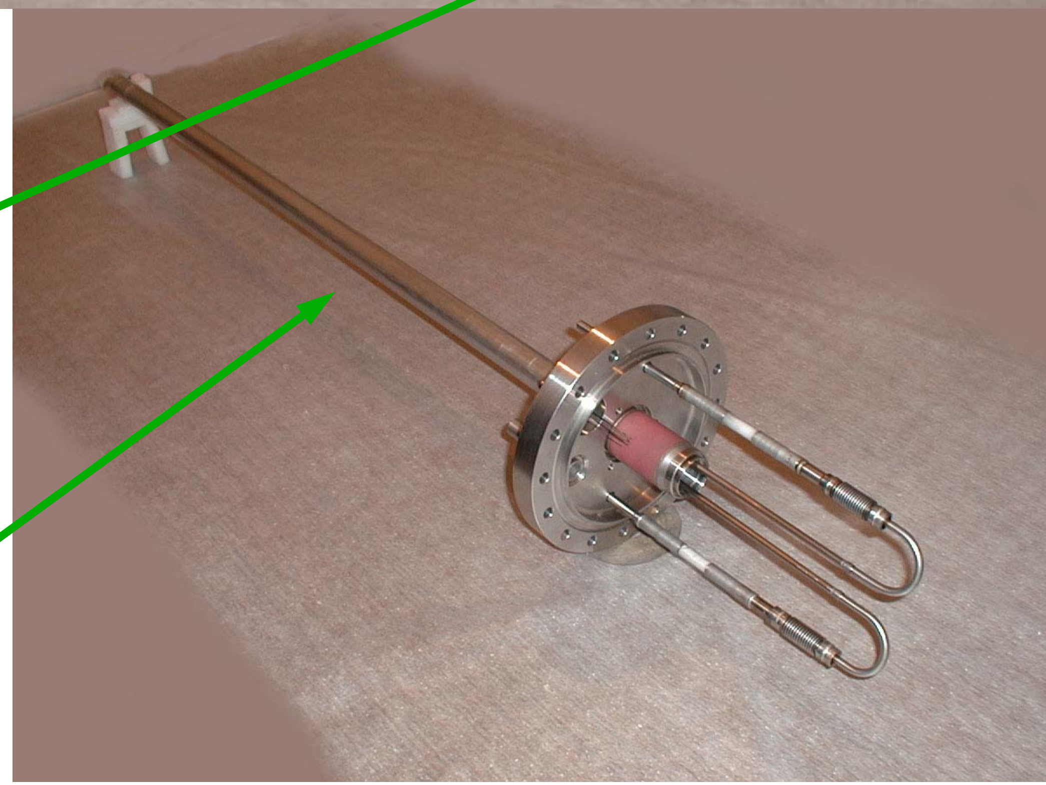


Low Energy Target Construction

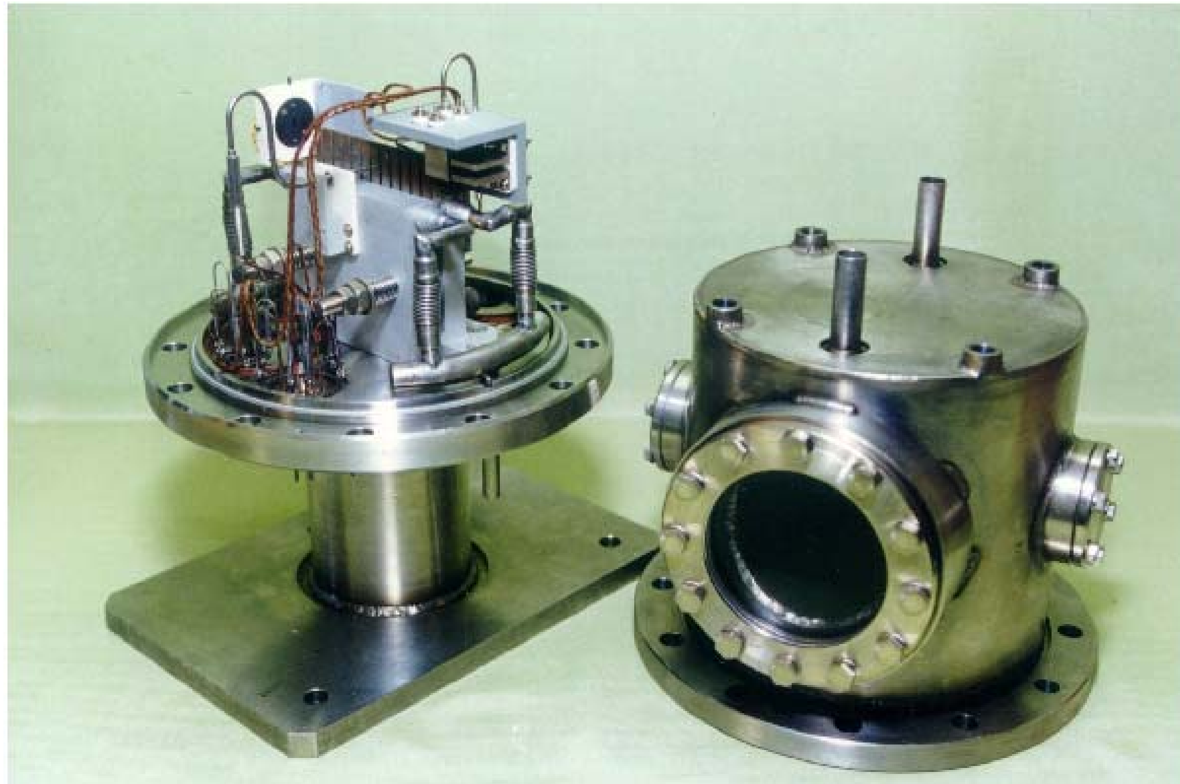
Graphite Fin Core $2\lambda_{int}$

Water cooling tube
provides mechanical support

Aluminum vacuum tube



Prototype Target Test



- Teeth show no damage after 7×10^{17} protons

- 3×10^5 pulses
- 2×10^{18} protons/mm^2 (~ 1 NuMI week)

- Max. stress pulses: 1×10^{13}/pulse 0.2 mm RMS spot

NuMI Design:
  4×10^{13}/pulse
  0.9 mm spot, 23MPa stress (cf 100MPa limit)

- If go to 1.6MW beam, require spot size →2.0mm
  - Maintains target temperature
  - Maintains target stress
  - Long-term radiation damage?

Target and Horn Modules

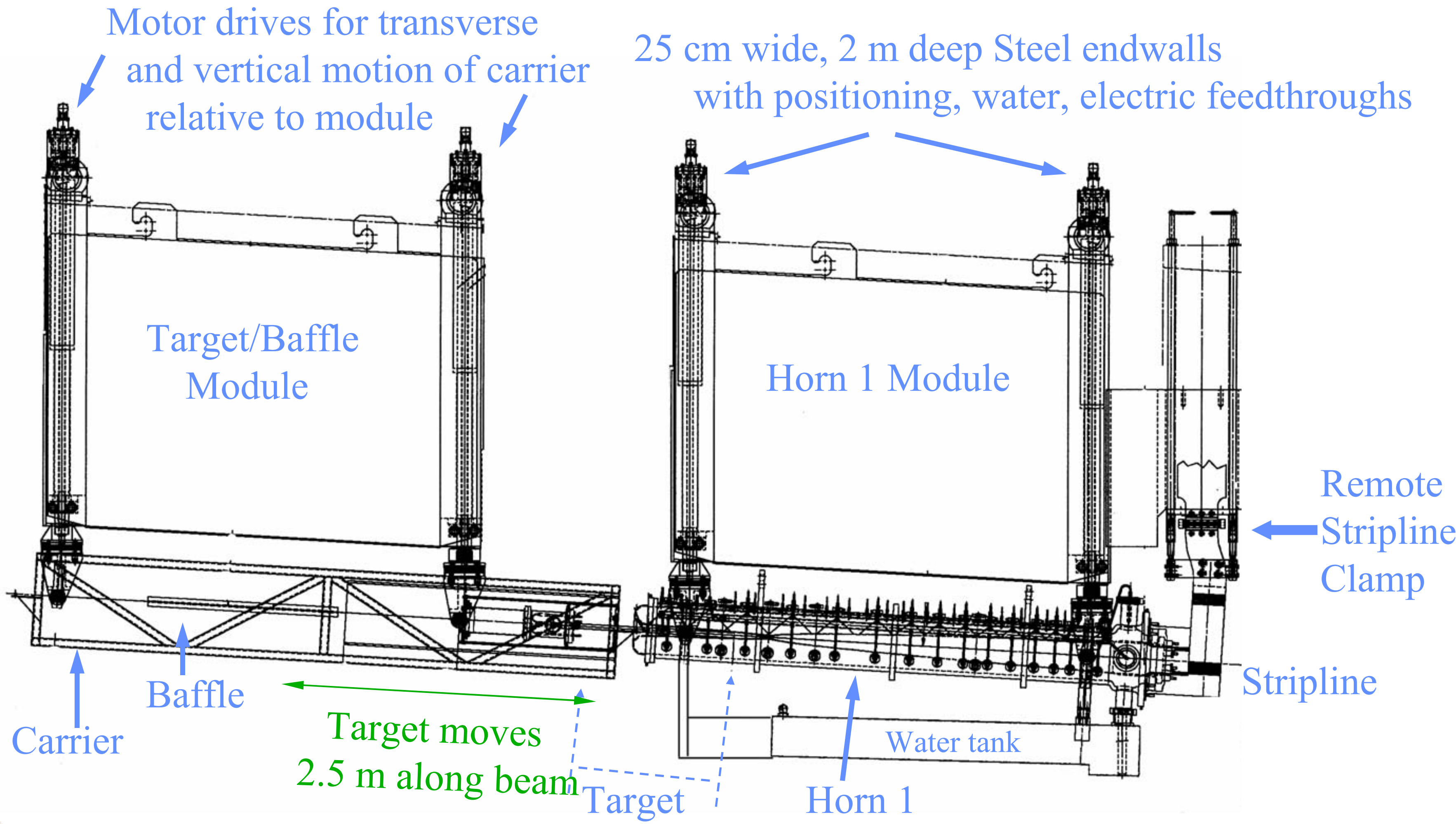
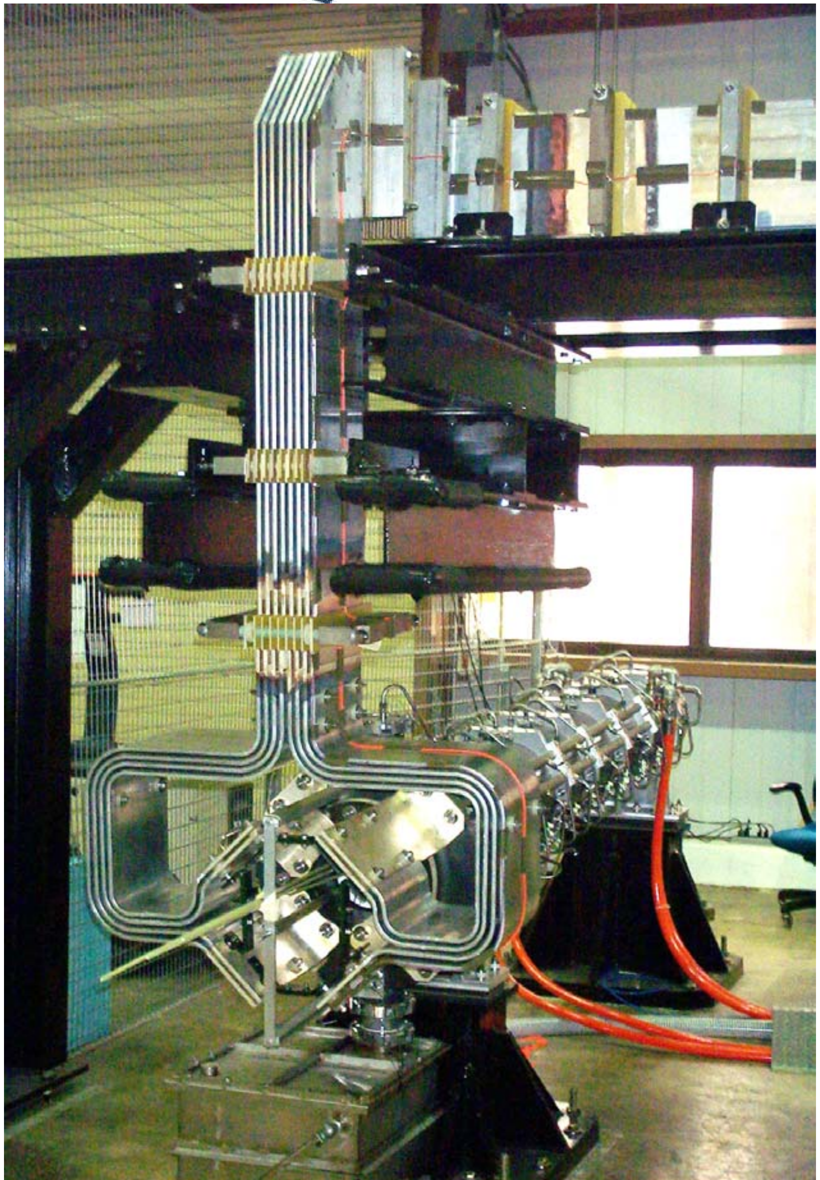
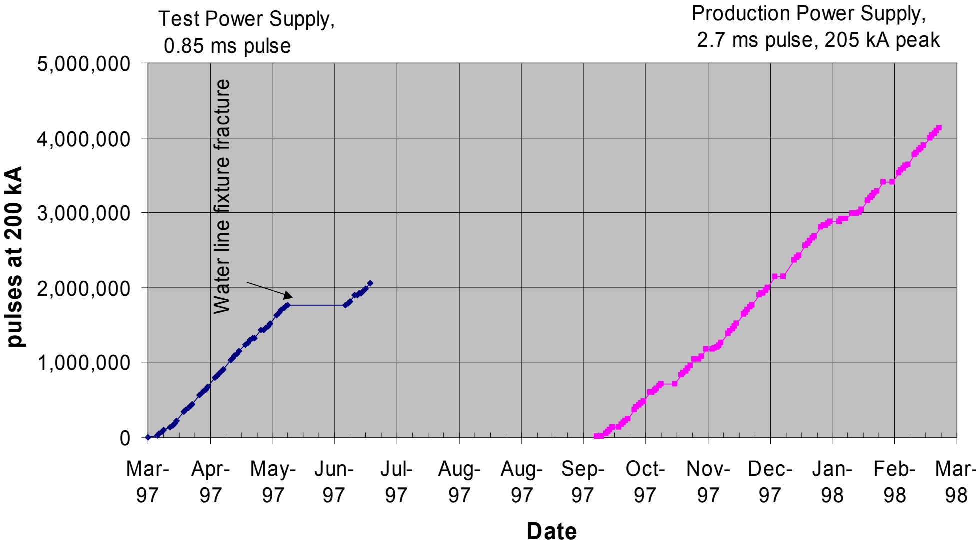
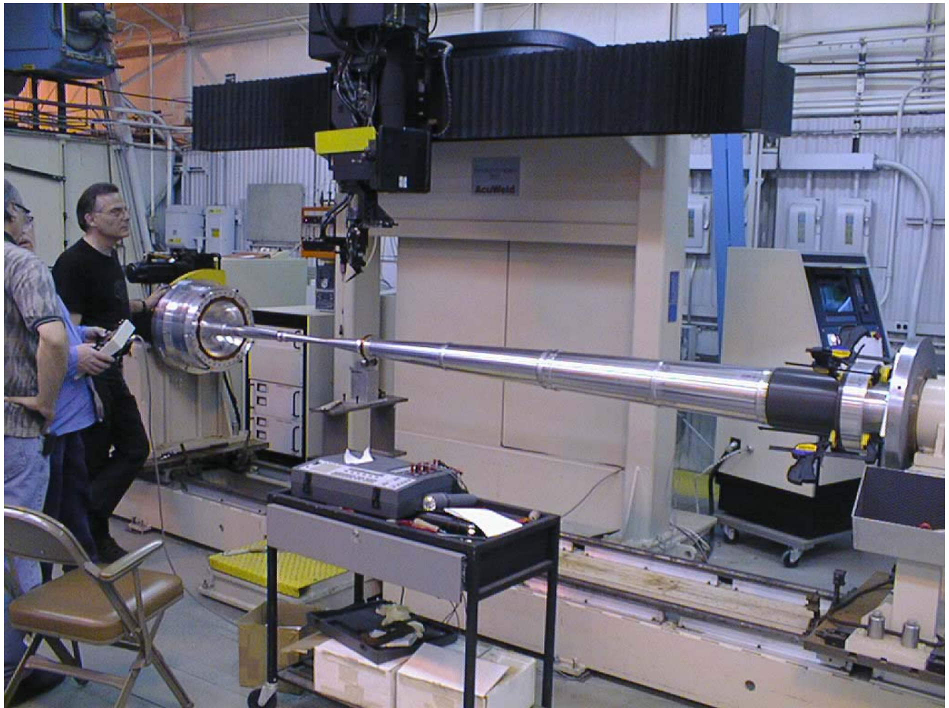


figure courtesy E.Villegas

Horn 1 Prototype

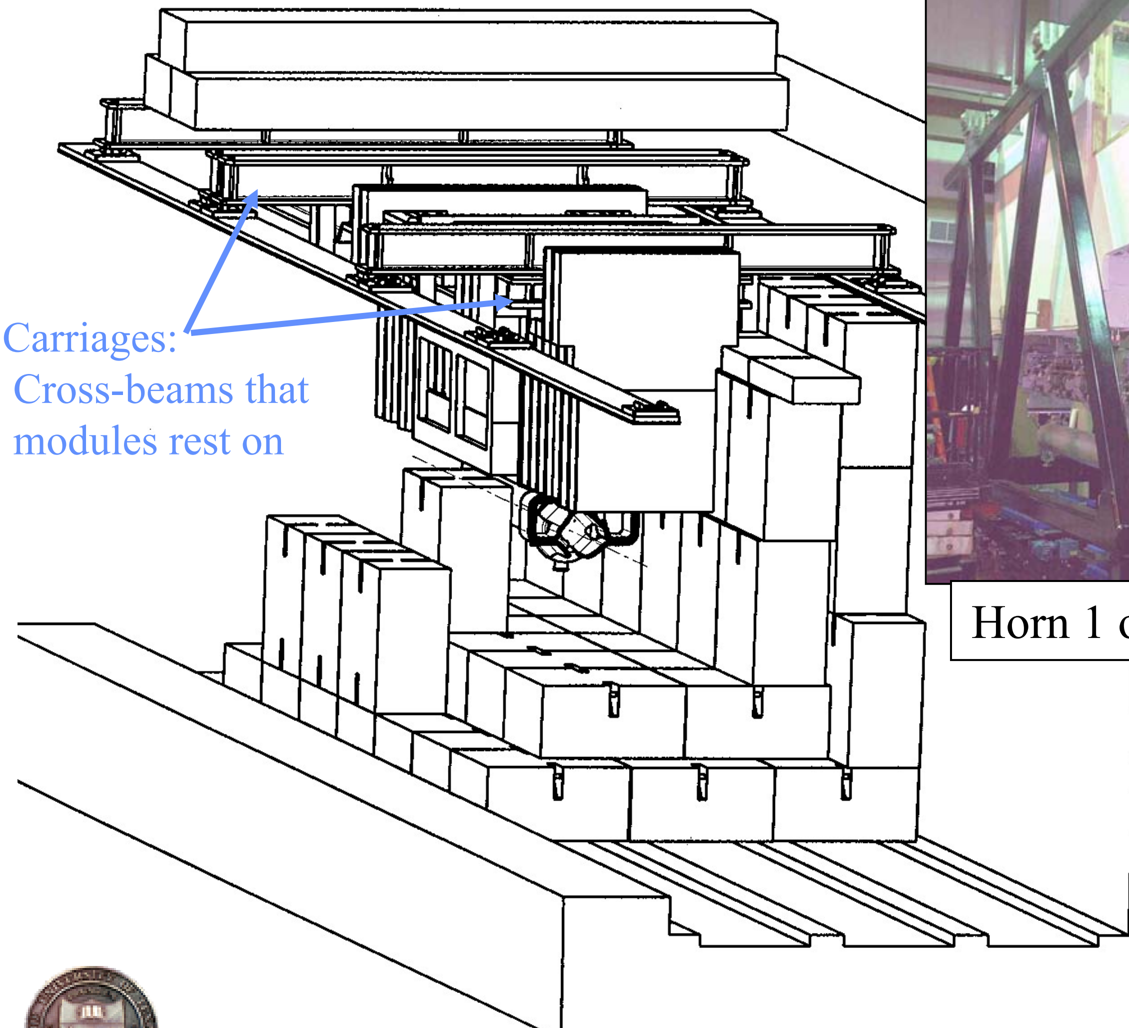


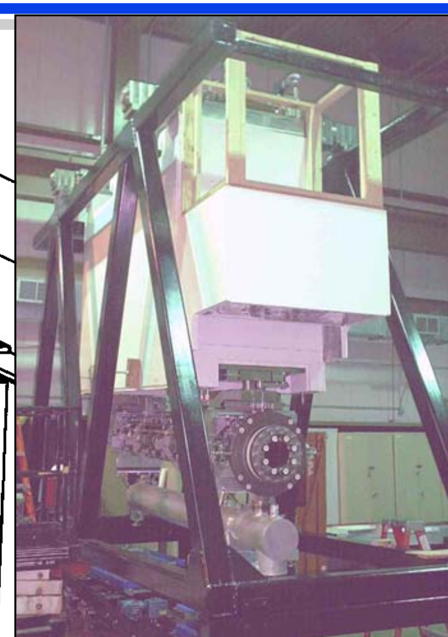




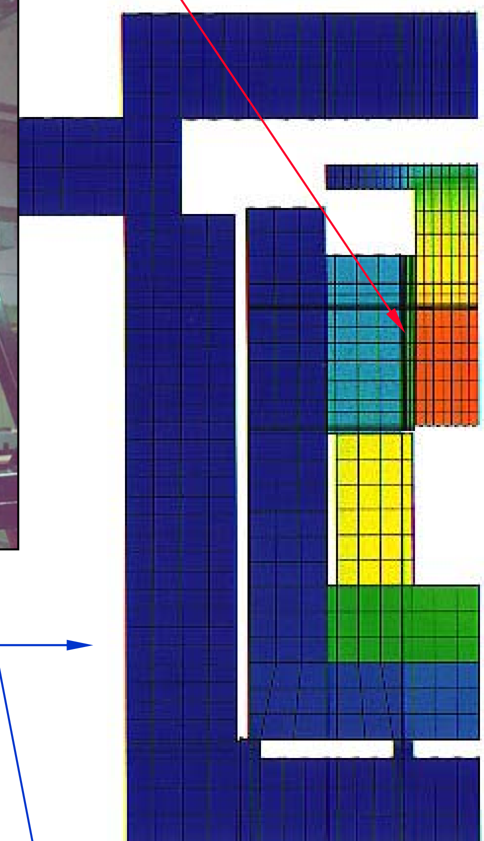
Target/Horn Module Carriages

Carriages:
Cross-beams that modules rest on

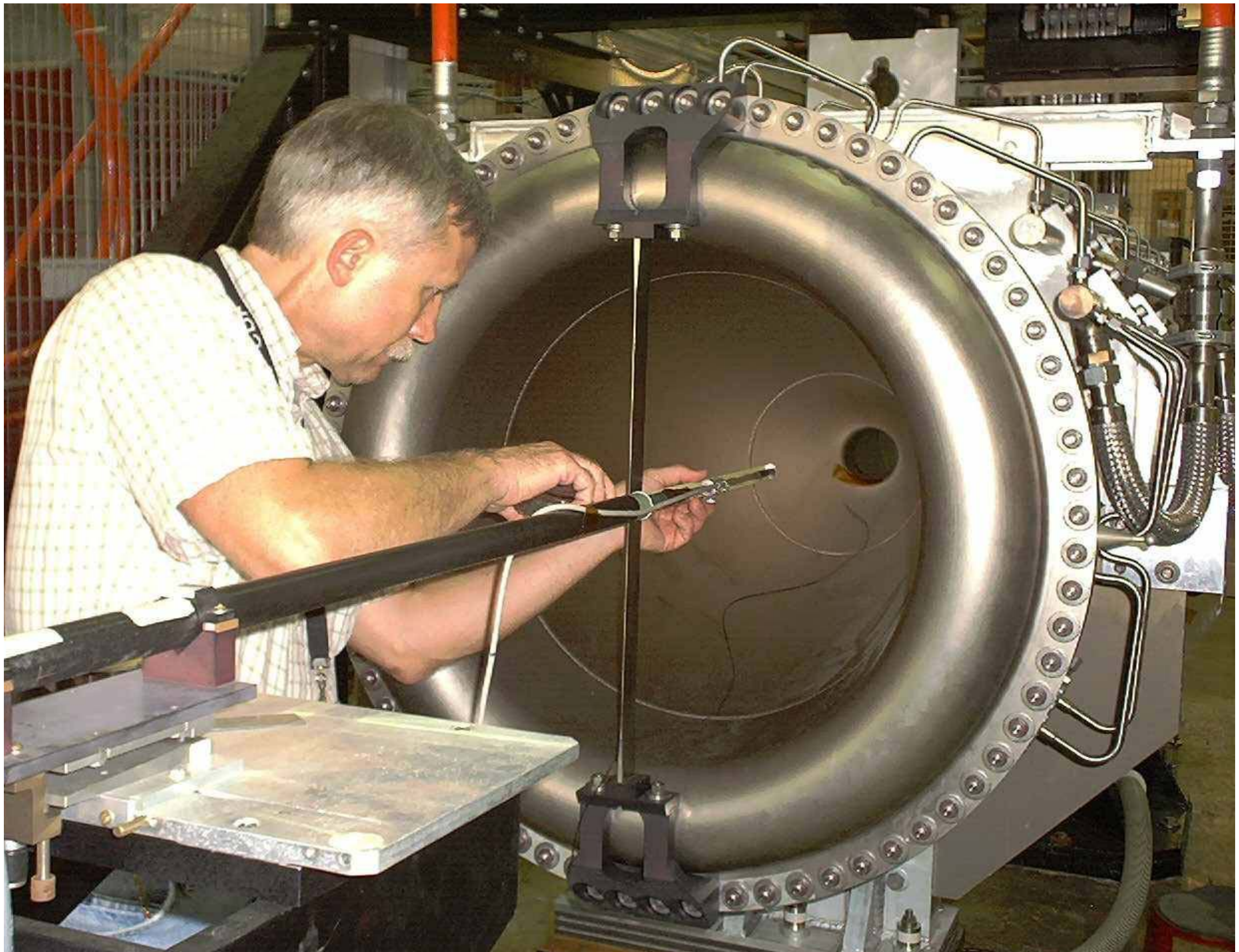




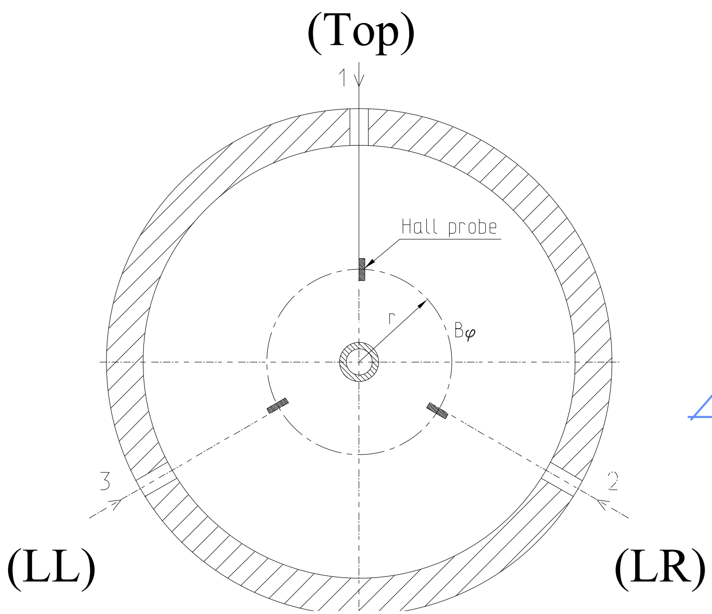
Horn 1 on module



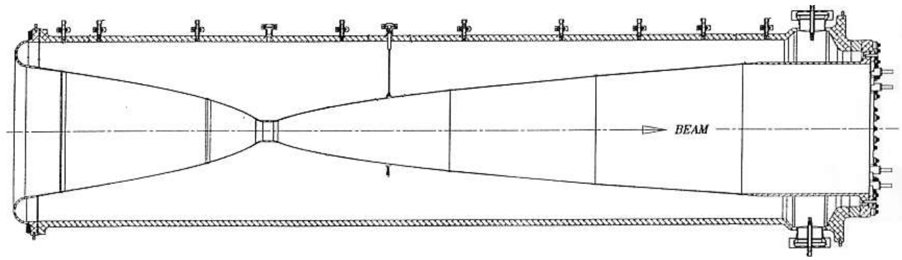
Production Horn 2 is Complete

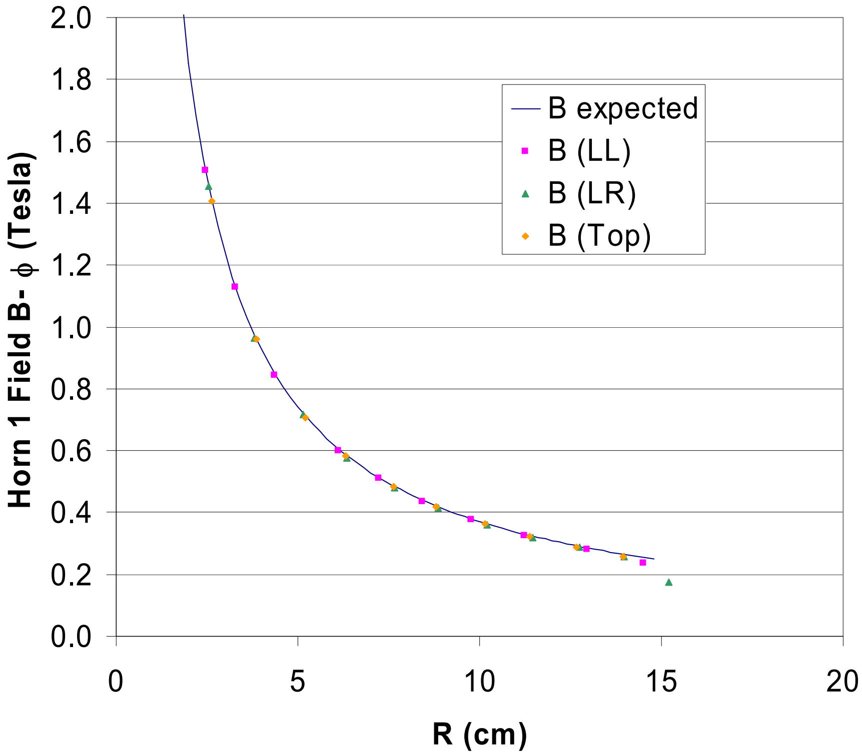


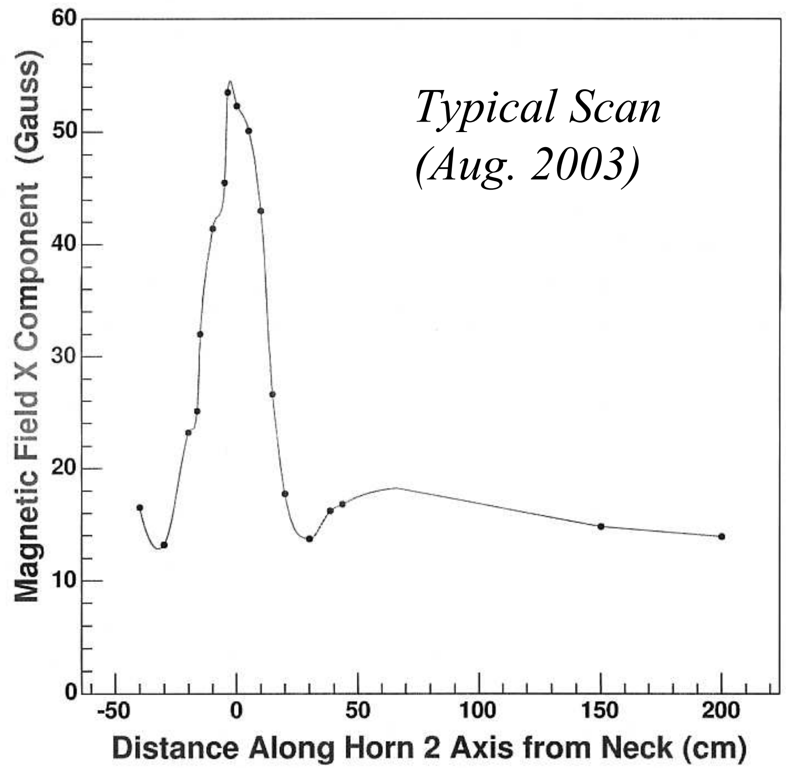
Horn Field Measurement



Measurement with probe
moving along horn axis

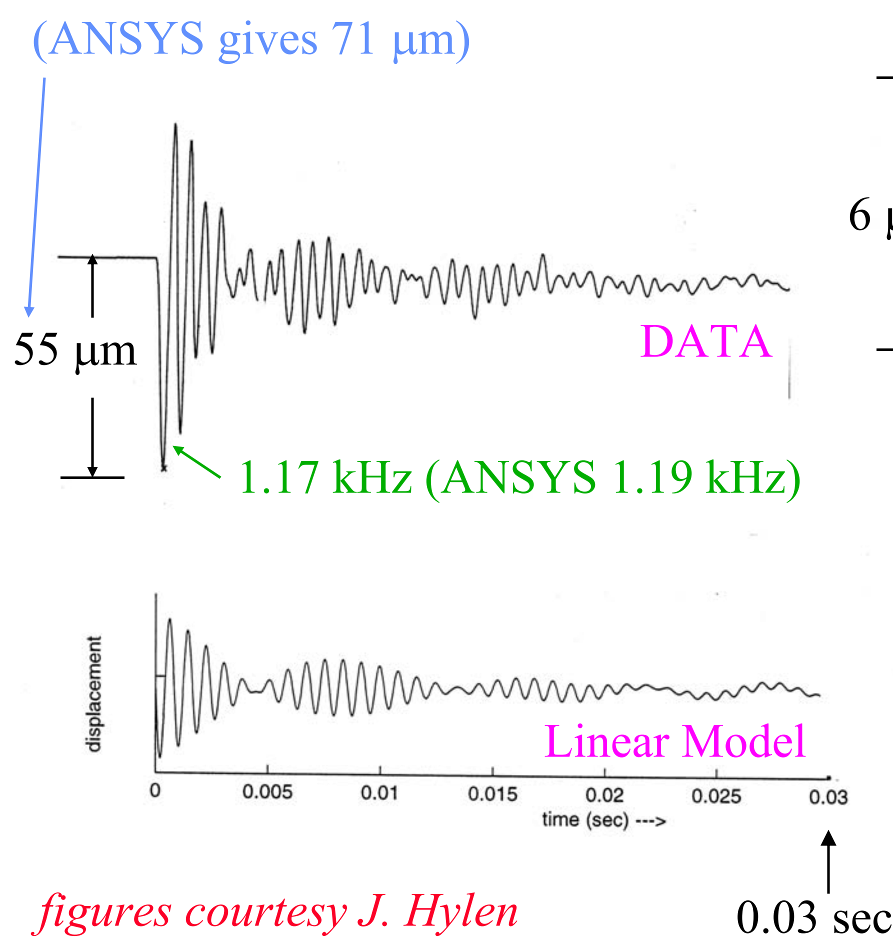


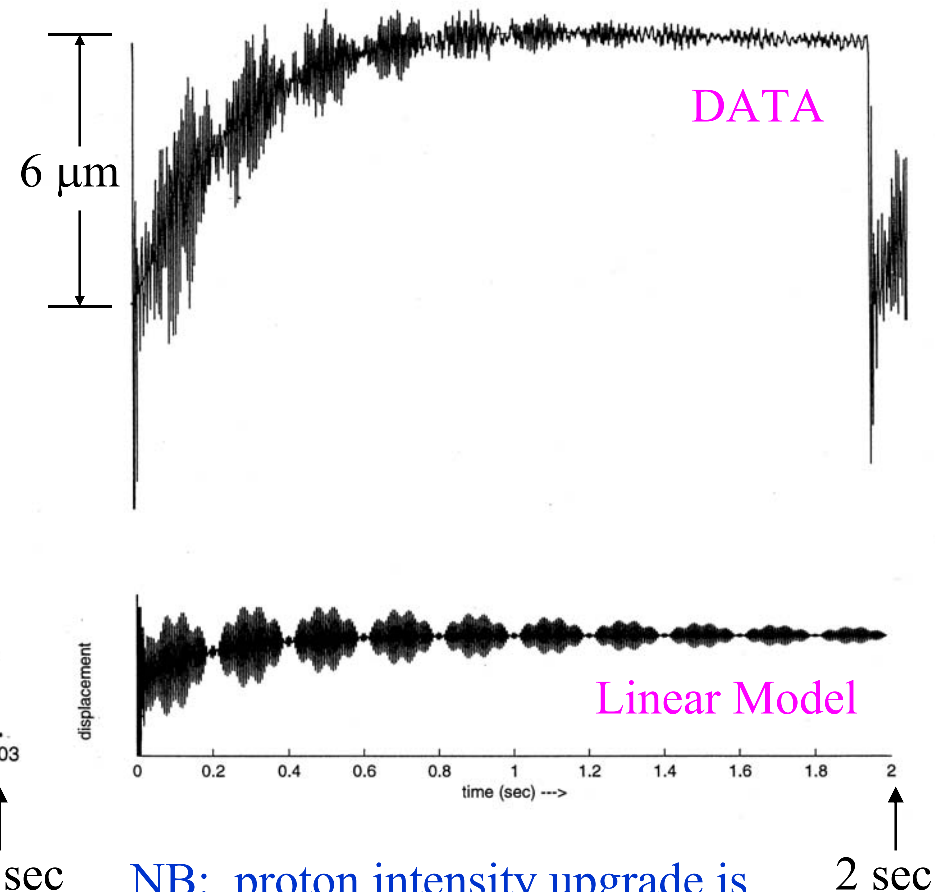




NuMI Horn 1

Vibration Measurement on Horn Bell Endcap

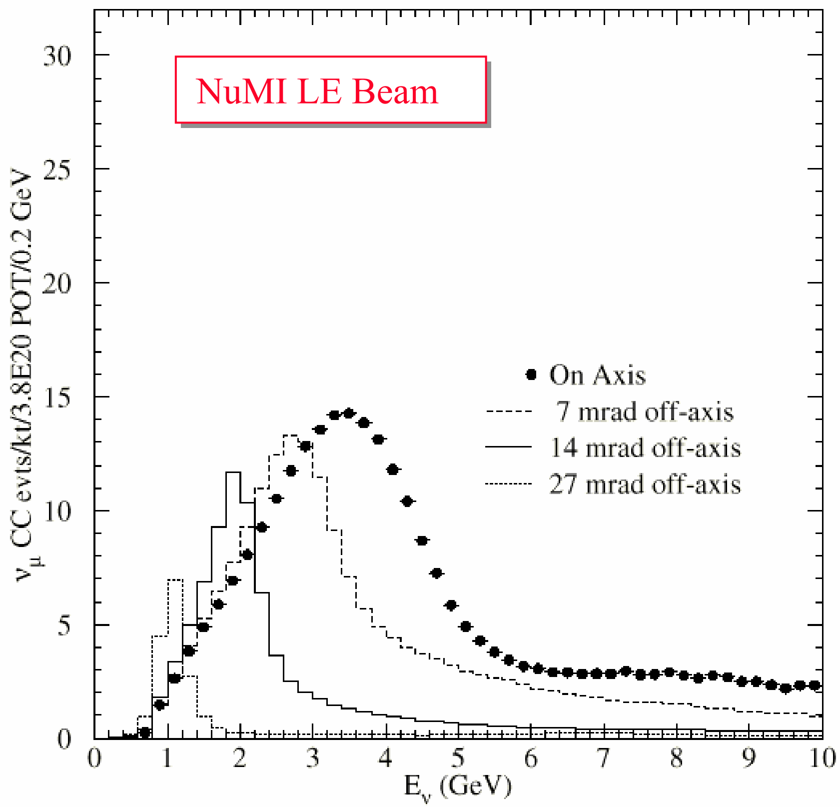


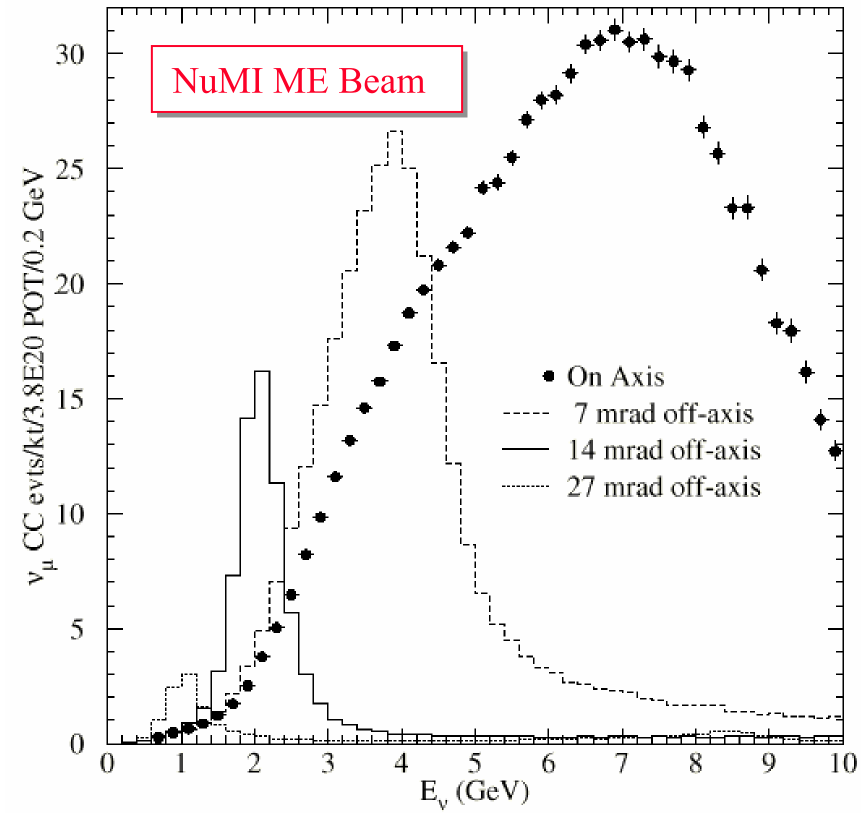


figures courtesy J. Hylen

NB: proton intensity upgrade is non-trivial if it requires faster rep-rate.

Off-Axis Beam from NuMI



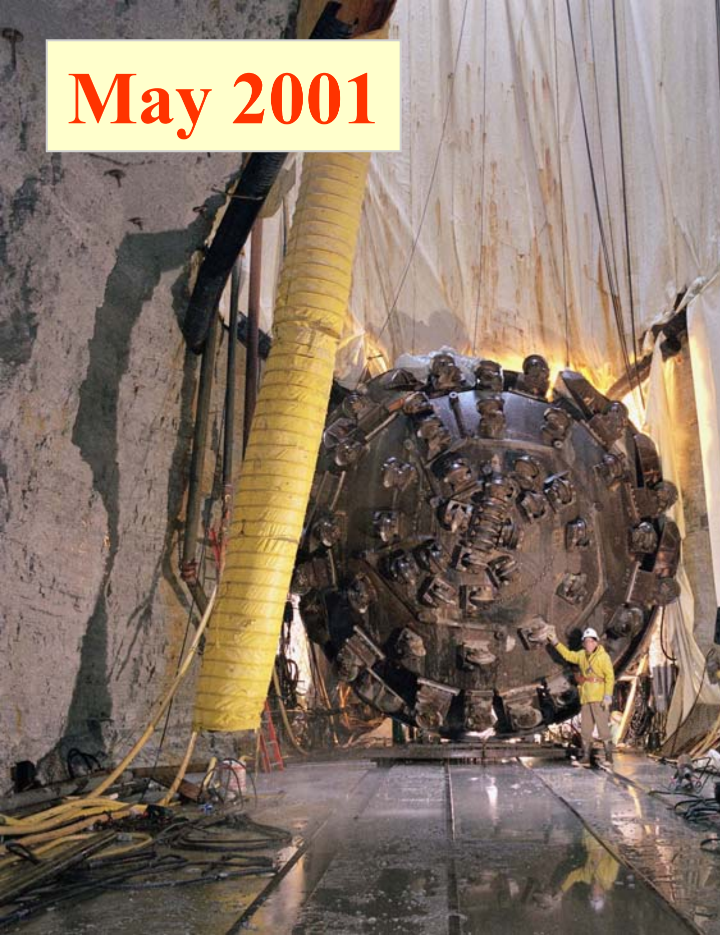


figures courtesy M.Messier

- Plots assume current neutrino target, horns.
- Variable target position can help move peaks dynamically
- Antineutrino running takes factor 3 hit in rate

Decay Tunnel

- Over 1 km of tunnel
- 7m diameter TBM

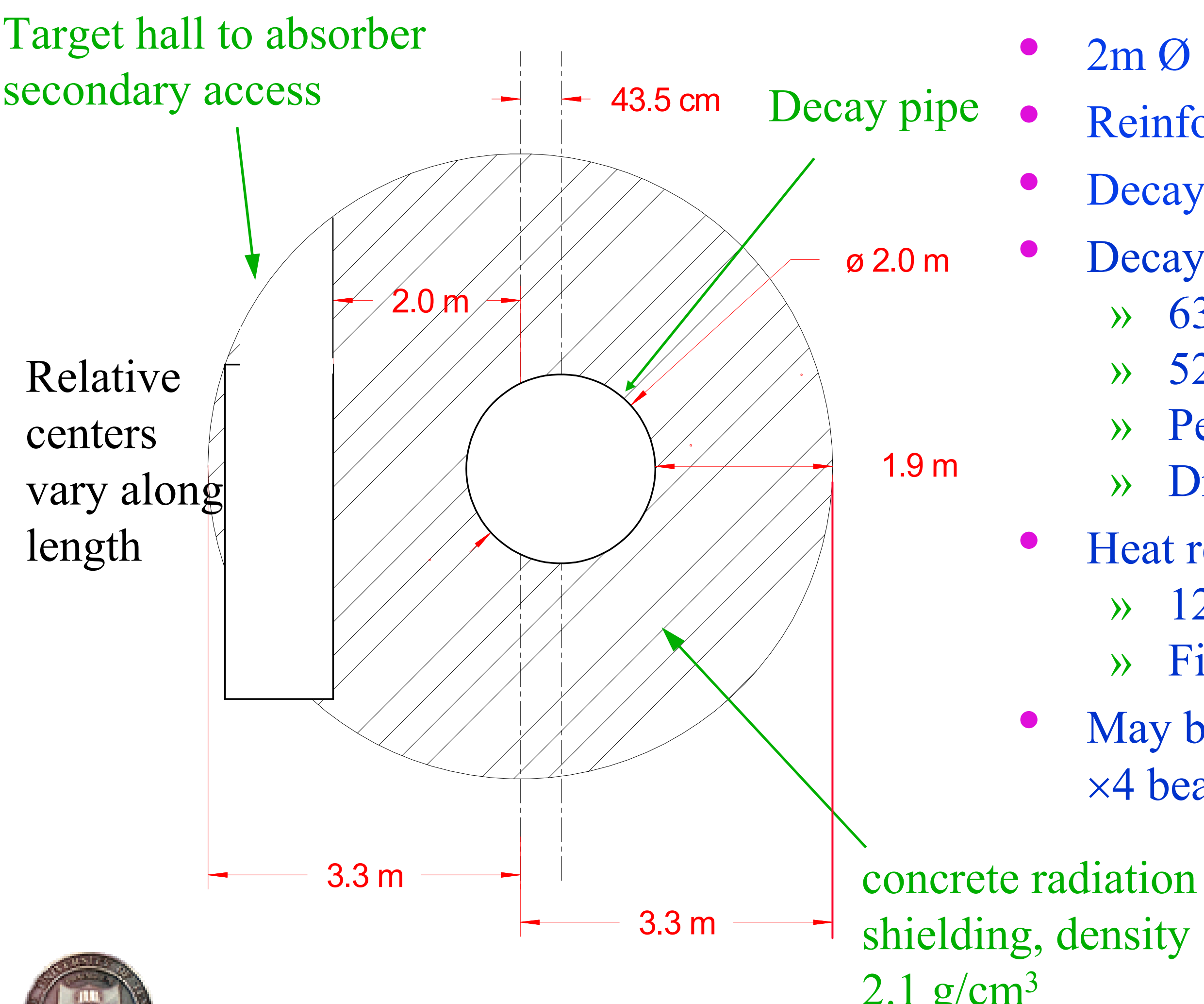


May 2001

TBM - front

July 2001

Cross Section of Pipe / Shielding

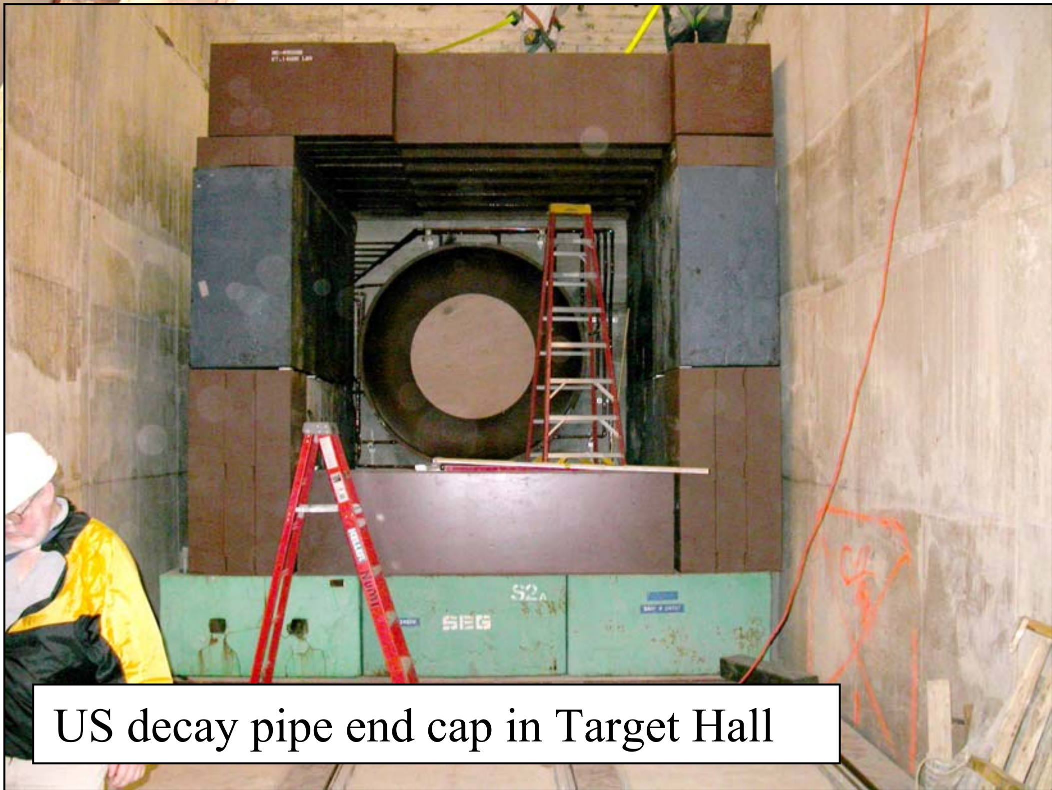


- 2m Ø steel cans, 1 cm wall.
- Reinforced by 4” rings @ 20 ft.
- Decay volume ~0.1-1.0 Torr
- Decay region power deposition
  - » 63 kW in steel decay pipe
  - » 52 kW in shielding concrete
  - » Peak deposition ~360 W/m
  - » Drops to 20 W/m (at ~610 m)
- Heat removed by water-cooling
  - » 12 plastic-coated copper lines
  - » Final temperature ~ 50^{o}C
- May be expensive to upgrade for ×4 beam intensity.

Decay Pipe in Shielding

- Dual entrance window
  - »Inner 1m Ø = 1.5mm Al
  - »Outer 2m Ø = 1.0 cm Fe

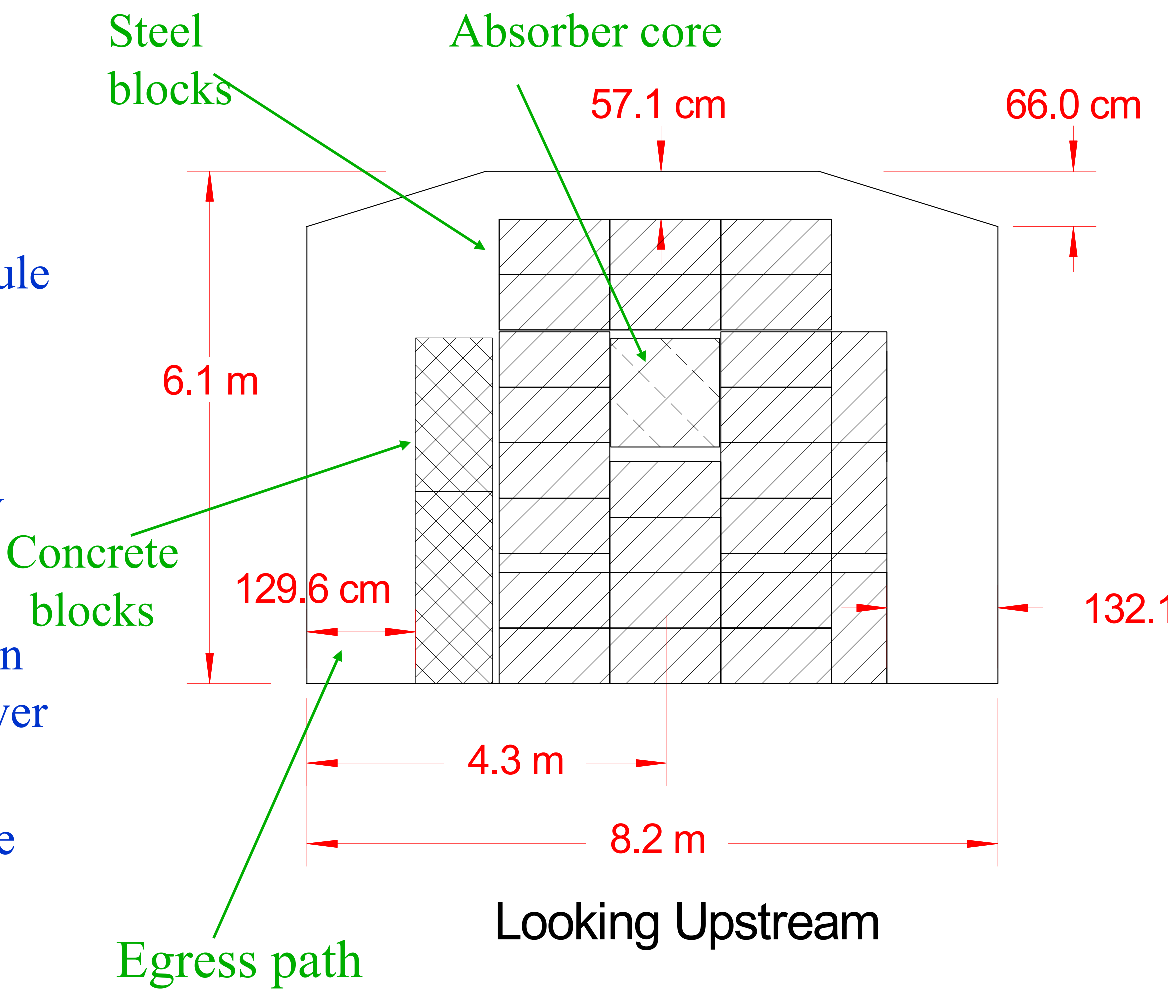
- Window should readily handle increase in beam power (currently designed for beam accident)



US decay pipe end cap in Target Hall

Beam Absorber

- Absorber core
  - » 8 aluminum plates
    30.5 x 129.5 x 129.5 cm^3
  - » dual water-cooling paths
  - » 8 kW peak power in one module (normal beam conditions)
  - » followed by 10 plates of steel, each 23.2 cm thick.
- Total power into Absorber: 60 kW
  (400 kW beam power if accident)
- Water-cooled Aluminum easily can accommodate increased beam power from proton upgrad
- Steel is more problematic – require adding water cooling?



Summary of NuMI Upgradeability

Item	4E13 ppp (1.9sec rep)	8E13 ppp (1.9sec rep)	1.5 E14 ppp (1.9sec rep)
Radiation Issues	OK	seal chase more	seal chase more
Primary Beam and Power Supplies	OK	OK	OK
Target and Target Cooling	OK	OK	New Target and Cooling
Horns and Cooling	OK	OK	OK
Target Chase Cooling and Shielding	OK	**cooling for stripline?**	**Cooling for whole chase**
Hadron Absorber Cooling	OK	probably OK	Additional cooling needed
Decay pipe cooling	OK	**requires study**	**need cooling**
Additional Cooling ponds	OK	may need	will need

table courtesy N. Grossman

Summary

- NuMI is substantial investment in US HEP program
- Design is flexible to permit variations, upgrades
  - »Adjustable neutrino beam energy
  - »Large target hall cavern to permit new focusing elements
  - »Conservative design parameters permit intensity upgrades
- We have maintained aggressive schedule
  - »Rebaselined project in Dec '01
  - »Completion of tunnel excavation late '02
  - »Commence upstream installation mid '03
  - »Commence downstream installation Feb '04
  - »Will commission Oct '04, ready Dec '04
- Lots more extensive documentation:
  - »*Letter of Intent to Build an Off-Axis Detector for NuMI,*
    www-numi.fnal.gov/new_initiatives/new_initiatives.html